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Preface

Fractals in geophysics

Geophysical phenomena of interest to geoscientists include both atmospheric and terrestrial related processes, which can be either static or dynamic. Characterization of such phenomena requires advanced models which often include scale invariance concepts of fractal or multi-fractal type. Recently, there has been much interdisciplinary interest in the application of geophysical processes. The application of fractals and multi-fractal concepts has given rise to a better understanding of the spatio-temporal organization of geophysical phenomena from micro to macro levels [1–6]. Wider application of these concepts to analyze and characterize space–time data requires a broad cross-disciplinary exchange among mathematicians, physicists and geoscientists. This special issue on "Fractals in Geophysics" contributes to this exchange of ideas. We hope that it will stimulate fruitful discussions among experts in geophysics and in core-geosciences.

The papers in this special issue have been classified based on the application of fractals and chaos to topics such as ocean, climatic and geophysical flow dynamics, porous media characterization and earth surface processes (e.g. channel networks, desertification, floods, earthquakes etc). These papers address various application areas of geophysical importance like climatic dynamics, earthquakes, porous media, river networks, vortex-flow, mineralogy, ocean dynamics, vegetation patterns in deserts, and soils. In particular, the following aspects are emphasized: (a) Theory and applications of scaling, fractals, and multi-fractals to quantify and characterize geophysical phenomena; (b) Techniques, algorithms, for estimation of (multi-)fractal exponents and dimensions, the characterization of attractors and time series, and the simulation of geophysical processes using multi-fractal models; and (c) Modeling of space–time geophysical phenomena.

In the first article of this issue, construction of patterns over one, two and three-dimensional spaces is explained by Carlos Puente. He provides certain examples found in geophysical applications that include irregular and crystal-like patterns.

Donald Turcotte describes the advantages of application of cellular automata theory [7] to deal with certain geological and geophysical problems, which cannot be solved by continuous mathematics effectively. This paper describes several successes of this approach in simulations of channel networks through diffusion limited aggregation (DLA) and in understanding avalanches and earthquakes through self-organized criticality.

Understanding chaotic advection phenomenon is important in geophysical flows. In their paper, Xavier Leoncini, Leonid Kuznetsov, and George M. Zaslavsky provide qualitative insights on general transport properties of two-dimensional flows, specifically geophysical flows. Fractal aspects of transport are developed to link their anomalous features to the fractal nature of the topology of the flows. Further, using a nice fractional kinetic analysis, the transport exponent is linked with the trapping time exponent.

Peter Chu carries out a multi-fractal analysis of a high-resolution temperature data set to determine the non-stationarity and intermittency of the upper layer (300 m depth) in the Southwestern part of Greenland Sea, Iceland Sea, and Norwegian Sea (GIN Sea). Such a study is of great use in better understanding oceanic convection process or the secondary circulation across oceanfronts.

Govindan Rangarajan and Dhananjay Sant apply fractal dimensional analysis to Indian climatic dynamics. In this paper, the time-series data of the major components of the climate—temperature, pressure, and precipitation are analyzed. Changes in climate variability changes from month to month and also from season to season are obtained. An interesting inference is made on how temperature and pressure in the February/March period influence the southwest monsoon rainfall.

Understanding the flow through fractal and multi-fractal porous media is an interesting topic in geophysics. Characterization of such flows effectively is a challenging task. In the subsequent two papers, such flows have been effectively characterized by applying novel nonlinear methods, and continuum percolation theory.

Veneziano and Essiam in their paper analyze the flow in a D-dimensional porous media under the condition that the hydraulic conductivity is an isotropic lognormal field with multi-fractal scale invariance. They have shown how

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hydraulic conductivity, hydraulic gradient, and specific flow vector satisfy multi-fractal scaling conditions. They derive consequences of multi-fractality of hydraulic gradient and specific flow vector in the frequency domain. In addition to these results, they have also shown how novel nonlinear methods can be used to analyze flow through random porous media.

Allen Hunt, in his paper, has applied continuum percolation theory to characterize a fractal pore space model. The unsaturated hydraulic conductivity is related to fractal characteristics. It is shown that fractal scaling of this conductivity crosses over to a percolation scaling above a moisture content threshold. Such a study is useful to characterize observed hydraulic properties of natural porous media.

Deriving size-number relationships of both pore and grain is another important activity in geophysics. It is understood through several remarkable studies that the pore and grain size distributions obey fractal power-laws. In the subsequent two papers similar studies have been presented.

A fractal model is constructed by Yongfu Xu and Ping Dong for the pore-size distribution of unsaturated soils. Several hydraulic properties of unsaturated porous media are derived, which are in good accord with experimental data published elsewhere, and expressed as the fractal dimensions and the air-entry value. These two parameters can be evaluated from the fractal model for both grain and pore-size distributions. Fractal dimensions are obtained for both grain and pore size distributions, and correlation between the pore and grain size distribution is also studied. Since both these distributions yield similar fractal dimensions, the fractal dimension of either of these size distributions can be used to determine the unsaturated hydraulic conductivity.

In the paper by Teo, Radhakrishnan and Sagar, pore space is isolated from a sandstone image by employing certain digital image processing techniques, with an intention to characterize the pore geometry. This pore space is decomposed into primitive elements of various sizes. Then, size-number relationship is tested and it is found that this exhibits a fractal power-law relationship.

By using swelling tests, swelling deformation and swelling pressure tests, which can be easily conducted in laboratory, Yongfu Xu, De'an Sun and Yangping Yao propose a method to estimate the surface fractal dimension of benotonite, which can then be used to calculate the maximum swelling strain and pressure. Using this method, they determine the surface fractal dimension of Wyoming benotonite and Tsukinuno benotonite.

Aggregated behavior of peak flows in channels is shown to exhibit statistical scale invariance at successively larger spatial scales. This scaling in peak flows is governed by self-similarity in channel networks. Vijay Gupta proposes a new mathematical framework based on scaling theory to interpret empirical scaling parameters in terms of numerical or analytical solutions of physical equations. This paper provides new insight into spatial scaling flood statistics and unifies them with physical processes.

A continuum model that involves positive feedback between vegetation biomass density and soil water density parameters for vegetation pattern in water limited systems is presented by Ehud Meron, Erez Gilad, Jost von Hardenberg, Moshe Shachak and Yayir Zarmi. This model predicts transitions from bare soil to various types of vegetation patterns at different levels of precipitation. Their scaling properties and associated phenomena are also studied. This paper suggests that desertification followed by recovery is a hysteresis loop and sheds light on the irreversibility of desertification.

Luciano Telesca and Maria Macchiato analyze the time-scaling properties of seismicity in the Umbroa–Marche region of central Italy during the 1997–1998 seismic crisis by means of the Detrended Fluctuations Analysis (DFA). Several interesting results related to scaling behavior have been presented in this paper.

Kazuyoshi Nanjo and Hiroyuki Nagahama examine the relationship between the estimated fractal dimensions of spatial distribution of aftershocks and pre-existing active faults. A positive correlation between the two dimensions is shown to imply that clustering of aftershocks reduces as the fractal dimension of active fault systems increases.

Marian Anghel presents an innovative method to measure the effective dimenisionality of a fault model that explores a wide parameter range from a crack like model to a dislocation model. This dimensionality is estimated by computing several modes to capture a certain fraction of the statistical variation of the surface deformation fields. Conclusions made in this paper are supported by direct dimension estimates using the correlation dimension.

Gabor Korvin and Klavdia Oleschko have presented a study on how multiple scattering can affect the fractal dimension estimated from the scattered wave field's Fourier spectrum.

Nikora and Goring, in their paper present various aspects of bulk statistics and spectral scaling of Martian topography and also include comparisons with Earth topography. Authors conclude that it can be approximated as a Gaussian random field. Two different scaling exponents for the power spectrum at two different scaling lengths are found. These results will be useful to develop a better understanding of the scaling in topography formed by different mechanisms (deposition, landslides, flowing water, etc.).

Bellie Sivakumar, in the final paper of this issue, gives a comprehensive review of the application of chaos theory in geophysics. He has given a comprehensive account of achievements in understanding and predicting geophysical phenomena through chaos. He also discusses identification and characterization of chaos, the state of chaos theory in geophysics. Future prospects are highlighted. Also included is a discussion on how chaos theory is useful as a bridge between the stochastic and deterministic aspects of nature.

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